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Hydrologic Performance of an Everglades Stormwater Treatment Area-STA6: A Constructed Wetland

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HYDROLOGIC PERFORMANCE OF AN EVERGLADES STORMWATER TREATMENT AREA-STA6: A CONSTRUCTED WETLAND

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UMMARY:
rge scale constructed wetlands known as Stormwater Treatment Areas (STAs) are being used in south Florida to reduce total phosphorus ncentrations (TP) in agricultural drainage/runoff and other waters. STA6 is a two- cell, 352 ha constructed wetland that has been in eration since December, 1997. Initial data indicates a significant reduction of TP with an average inflow concentration of 0.057 mg L^{-1} and tflow concentration of 0.018 mg L^{-1}.

eywords: Constructed Wetland, Everglades, Drainage, Stormwater, Water Quality, Water reatment, Wetland Hydrology.

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ABSTRACT

The 1994 Florida's Everglades Forever Act mandates the construction of large scale constructed wetlands known as Stormwater Treatment Areas to reduce total phosphorus in agricultural runoff/drainage waters from the Everglades Agricultural Area and other water that flow south to the Everglades Protection Area. An Everglades regulatory program has been established to achieve a minimum TP load reduction of 25% in agricultural drainage/runoff from the Everglades Agricultural Area basin through the implementation of various agricultural best management practices. The Stormwater Treatment Areas are designed to further reduce total phosphorus to an initial concentration of 0.05 mg L^{-1}. STA6, Section 1 is the first of the Stormwater Treatment Areas to be built other than the 1544 ha proto-type, the Everglades Nutrient Removal Project, that has been successfully operating since August of 1994. STA6 Section 1 has a total treatment area of 352 ha with two cells in parallel. It has been in operation since December, 1997. So far, 65% reduction of TP concentration has been observed at the outflow from an average daily hydraulic loading rate of 6.25 cm per day and average retention time of 8 days. This paper presents the design, operation, monitoring network and available data for STA6, Section 1.

Keywords: Constructed Wetland, Everglades, Drainage, Stormwater, Water Quality, Water Treatment, *Wetland Hydrology.*

INTRODUCTION

Ecological changes in the subtropical Everglades ecosystem that resulted in alterations of the magnitude, type and order of flora and fauna in the last several decades have been attributed to hydropattern changes and increased nutrient levels in inflow waters (Davis, 1991; Koch and Reddy, 1992; Swift and Nicholas, 1987). Most of the surface water inflows to the upper reaches of the Everglades are outflows from the Everglades Agricultural Area (EAA). The EAA is a 237,650 ha (587,000 ac) organic soil irrigation and drainage basin where 84% of the production is sugarcane (Figure 1). The primary water control structures are around Lake Okeechobee and the EAA perimeters. Four primary canals (Miami, North New River, Hillsboro, and West Palm Beach canals) supply irrigation water from Lake Okeechobee, and carry out drainage/runoff from the EAA. The secondary system is composed of farm pump stations, mains, laterals and field ditches. Generally, irrigation water is withdrawn under gravity from the primary canals and farm drainage/runoff is pumped out. The area receives 1329 mm (52.3 in) of annual rainfall on average, with 66% occurring in the wet season (June through October). The annual mean historical drainage/runoff ranged from 33,982 ha-m (275,485 ac-ft) to 191,172 ha-m (1,549,793 ac-ft) with a mean of 114,816 ha-m (930,790 ac-ft) as reported in Abtew and Khanal (1994).

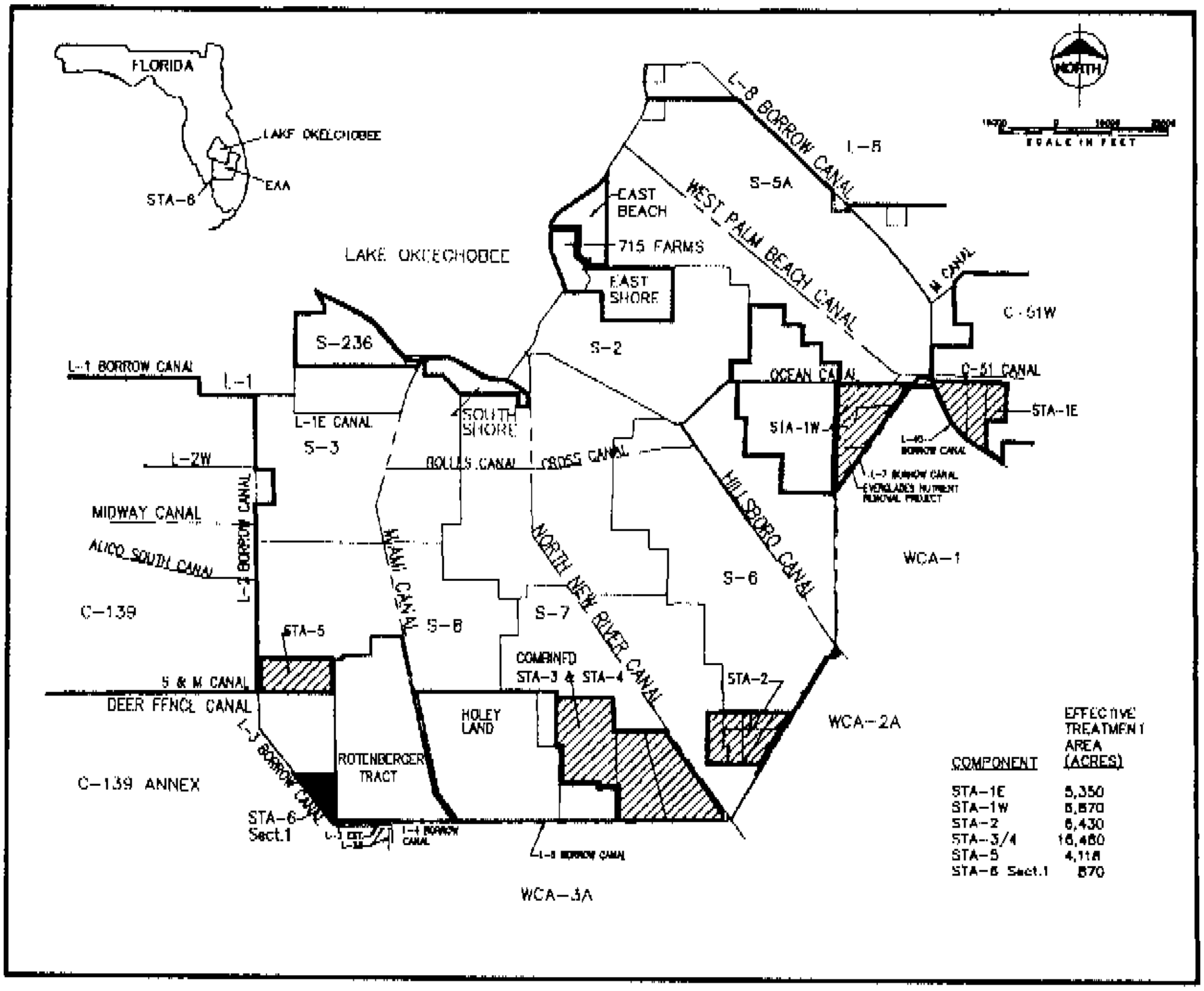

Figure 1. Map of the Everglades agricultural Area and the Stormwater Treatment Area Locations.

The 1994 Everglades Forever Act (State of Florida, Section 373.4592) mandates the South Florida Water Management District to implement the Everglades Construction Project (ECP). The Everglades Construction Project's objective is the design and construction of over 16,800 ha of Stormwater Treatment Areas at six locations: STA-1E, 2166 ha (5350 ac); STA-1W, 2781 ha (6870 ac); STA2, 2603 ha (6430 ac); STA3/4, 6672 ha (16480 ac); STA5, 1667 ha (4118 ac) and STA6, Section 1, 352 ha (870 ac); STA6, Section 2, 571 ha (1410 ac). These STAs generally are located at the southern and southeastern boundaries of the EAA (Figure 1). Construction completion dates are January 1999 for STA5 and STA-1W; February 1999 for STA2; July 2002 for STA-1E and October 2003 for STA3/4. Completion date for STA6, Section 2 is not available. This paper presents the design and operation of the first of the STAs, STA6 Section 1. Also, preliminary data on the hydrologic and treatment performance is presented.

SITE DESCRIPTION

STA6 Section 1 is the first of the Stormwater Treatment Areas to be constructed other than the 1,544 ha proto-type constructed wetland, the Everglades Nutrient Removal Project, that has been successfully operating since August, 1994 (Abtew et al., 1995). STA6 is located at the southeastern corner of Hendry county and the southwest corner of the EAA at Lat. 26° 21' 36" and Long. 80° 54' 21" (Figure 1). STA6 Section 1 has been designed to provide a total effective treatment area of 352 ha. It has two cells in parallel: Cell 5 (253 ha or 625 ac) and Cell 3 (99 ha or 245 ac) as shown in Figure 2. Since 1989, the two cells have been operated as a storm water retention area by the United States Sugar Corporation, USSC (SFWMD, 1997). Approximately 4,210 ha of USSC's agricultural production area drains into STA6 Section 1 via a supply canal (Figure 2) through an existing pump station G600. The average annual design inflow is 2,225 ha-m (18,034 ac-ft) per year as authorized in Surface Water Management (SWM) Permit No. 26-00041-S issued by South Florida Water Management District (SFWMD, 1997).

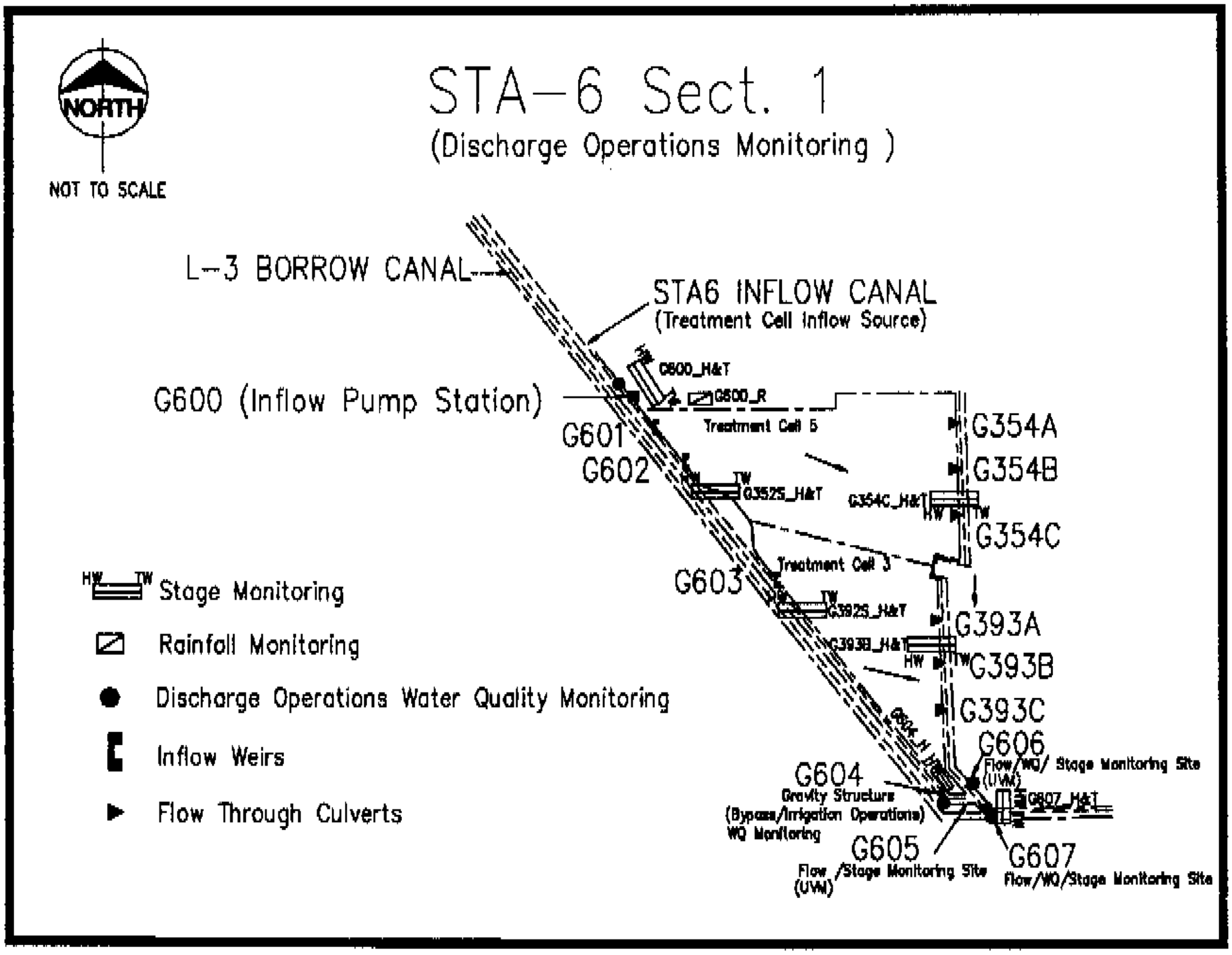

Figure 2. Stormwater Treatment Area (STA6), Section 1

General observations of vegetation coverage of the site are summarized as follows (R. Meeker, SFWMD, personal communications). Cell 5 is composed of a mix of vegetative types, including emergent macrophytes, submersed macrophytes, and periphyton. It is divided into three distinct zones, with a different community dominating each zone. The western (inflow) side of the cell is dominated by cattail (*Typha sp.*) and torpedo grass (*Panicum repens*), but several other emergent plant species such as willow (*Salix sp.*), arrowhead (*Sagittaria sp.*), and pickerelweed (*Pontederia cordata*) are also found. The central portion is dominated by a submersed macrophyte and periphyton community. The eastern (outflow) side of Cell 5 is dominated by a para grass (*Panicum purpurascens*) and submersed algae complex. Cell 3 is more uniform in its coverage of plant species and is not divided into discrete communities as in Cell 5. The entire cell is dominated by sawgrass (*Cladium jamaicense*), but several other species can be found growing here. Some of these include willow, arrowhead, and cattail. Average ground elevation in Cell 5 and Cell 3 is 3.768 m (12.36 ft) and 3.771m (12.37 ft) NGVD, respectively (SFWMD, 1997).

DESIGN AND OPERATION

Inflow from the supply canal is pumped through station G600. The pump station consists of five diesel pumps with a capacity of 2.83 $m^3 s^{-1}$ (45,000 gpm or 100 cfs) each, a design pump speed of 360 rpm, and a design head of 3.11 meter. The inflow pump moves water from the supply canal into the delivery canal that runs along the western edge of Cells 5 and 3. Water is delivered to Cell 5 from the delivery canal through Weir 1 (G601) and Weir 2 (G602), which are 3.35 meters (11 ft) wide trapezoidal broad-crested weirs, with 6 to 1 side slopes, and crest elevation of 4.27 meter (14.00 ft) NGVD. The design maximum flow rate is 5.09 $m^3 s^{-1}$ (180 cfs) per weir with headwater and tailwater elevations of 4.98 meter (16.34 ft) NGVD and 4.71 meter (15.45 ft) NGVD, respectively. Cell 3 receives water from the delivery canal through Weir 3 which is 4.57 meters (15 ft) wide trapezoidal broad-crested weir, with 10 to 1 side slope, and crest elevation of 4.36 meter (14.3 ft) NGVD. The design maximum flow rate is 3.96 $m^3 s^{-1}$ (140 cfs) with headwater and tailwater elevations of 4.91 meter (16.09 ft) NGVD and 4.72 meter (15.47 ft) NGVD, respectively.

Outflow from Cell 5 to the discharge canal is through three culverts (G354A, G354B, and G354C); aluminum corrugated metal pipes of 2.13-meter diameter and 22.9 meter length. At the inflow of each culvert, a weir box at crest elevation of 4.15 m (13.6 ft) NGVD controls the level of drawdown. The culvert invert elevation is 1.52 meter (5.0 ft) NGVD. Outflow from Cell 3 to the discharge canal is also equipped with three similar culverts with weir entrances (G393A, G393B, and G393C). Each of the six weir entrances to the culverts is equipped with slide gates to manually shutoff outflow when needed. The three culverts of Cell 5 are designed for a total outflow of 10.19 $m^3 s^{-1}$ (360 cfs) with headwater of 4.83 meter (15.85 ft) NGVD and tailwater of 4.62 meter (15.16 ft) NGVD. Cell 3 currently requires the use of only one culvert (G393B) for design outflow of 3.96 $m^3 s^{-1}$ (140 cfs) with headwater of 4.88 meter (16.0 ft) NGVD and a tailwater of 4.62 m (15.15 ft) NGVD. The discharge canal is designed to convey all discharge with its 10.4 meters (34 ft) bottom width at 0.0 meter NGVD and side slopes of 2.5 to 1. Outflow from STA6 enters the L-4 Borrow Canal through six culverts (G607) four of which are 168 cm diameter by 21.3 meter length and the other two are 213 cm diameter by 21.3 meter length. The L-4 Borrow Canal conveys flows eastward to the S-8 Pump station, which discharges into Water Conservation Area 3A (WCA 3A).

At the end of the supply canal there are two 168 cm diameter culverts (G604) with stop logs that can be used to bypass flows to the L-4 canal through the G607 culverts. Upon demand, irrigation water can be conveyed from L-4 canal backward to USSC Unit 2 farm via the supply canal through five 122 cm diameter culverts at G604, which are equipped with flap gates that allow flow to the north. The water use permit for USSC allows an irrigation withdrawal rate of 8.32 m^3s^{-1} (294 cfs) using two irrigation pumps.

Permit Requirements

Startup Phase and Discharge

Prior to discharge, the permit required the monitoring of total phosphorus (TP) concentration in STA6, Section 1 to demonstrate that the project is achieving a net reduction in TP. This period is referred to as the Startup Phase. Water depth management to facilitate recruitment of marsh vegetation was also required. Water samples were collected weekly at the inflow structure (G600) and at structures G354A, G354C, G393A and geometric mean of total water column phosphorus concentration were compared. Net reduction is achieved when the 4-week grab sample geometric mean TP concentrations of an average of three structures (G354A, G354C, and G393A) is lower than the 4-week flow weighted mean TP concentrations at the inflow (G600). This was a condition to allow discharging from STA6. The condition was met during the startup period of November 10, 1997 through December 1, 1997, and full operation (discharge) was started on December 9, 1997. Results of the startup water quality and flow monitoring are shown in Table 1. The four-week flow weighted mean TP concentration at the inflow structure (G600) was 0.0321 mg L^{-1} and the four-week geometric mean of the three outflow culverts (G354A, G354C, and G393A) was 0.0178 mg L^{-1}.

Table 1. STA6 Startup Total Phosphorus and Flow Monitoring.

Date	G600 Inflow 1000 m^3 (ft^3)	G600 TP mg L^{-1}	G354A TP mg L^{-1}	G354C TP mg L^{-1}	G393C TP mg L^{-1}
11/10/97	164 (5,780)	0.033	0.012	0.017	0.019
11/17/97	281 (9,915)	0.035	0.018	0.02	0.018
11/24/97	651 (23,021)	0.031	0.017	0.019	0.017
12/01/97	1,360 (48,047)	0.032	0.017	0.019	0.023

Stabilization and Operation

Following completion of the startup phase, Section 373.3592(9)(h) of the Everglades Forever Act (EFA) specifies that discharges shall be allowed to continue if after a stabilization period, the following is demonstrated:

a) STA6, section 1 is achieving the design objectives of the Everglades Forever Act for phosphorus.

b) For water quality parameters other than phosphorus, the discharge water quality is of equal better quality than the inflow.

c) The discharge does not pose a serious danger to the public health, safety, or welfare.

Stabilization period of STAs is generally anticipated to take 2 to 3 years. During that period, compliance will be evaluated based on one of the following conditions. A 12-month moving flow-weighted average of the outflow TP is equal to or less than 0.05 mg L^{-1}; or is less than the 12-month moving flow-weighted average TP concentrations at the inflow; or a trend towards achieving the first condition is shown. Other water quality parameters to be monitored are listed in Table 2. Compliance will be demonstrated if the 4-quarter moving average of the outflow meets state water quality standards or is better than the 4-quarter moving average at the inflow.

Table 2. STA6 Water Quality Monitoring Program Parameter List

Storet Code	Parameter	Unit
I. Physical Parameters		
00010	Water Temperature	°C
00300	Dissolved Oxygen	mg L^{-1}
00094	Conductance	µmhos
00400	pH	STD unit
82078	Turbidity	NTU
00080	Color	NTUS
00530	TSS	mg L^{-1}
II. Nutrients		
00665	Total Phosphorus	mg L^{-1}
00612	Ammonia	mg L^{-1}
00625	Nitrogen, Kjel	mg L^{-1}
00660	PO4 Ortho Phosphorus	mg L^{-1}
III. Major ions		
74010	Iron (FE) (total)	mg L^{-1}
00956	Silica	mg L^{-1}
00945	Sulfate	mg L^{-1}
00410	Alkalinity	mg L^{-1}
00940	Chloride (dissolved)	mg L^{-1}
00929	Sodium (dissolved)	mg L^{-1}
00937	Potassium (dissolved)	mg L^{-1}
00916	Calcium (dissolved)	mg L^{-1}
00927	Magnesium (dissolved)	mg L^{-1}

Storet Code	Parameter	Unit
IV. Trace Metals		
01097	Antimony	µg L^{-1}
01105	Aluminum	µg L^{-1}
01012	Beryllium	µg L^{-1}
01027	Cadmium (total)	µg L^{-1}
01042	Copper (total)	µg L^{-1}
01051	Lead	µg L^{-1}
01067	Nickel	µg L^{-1}
01147	Selenium	µg L^{-1}
01077	Silver	µg L^{-1}
01059	Thallium	µg L^{-1}
01092	Zinc (total)	µg L^{-1}
00900	Hardness	mg L^{-1}
V. Pesticides in Water (Organophosphorus and nitrogen Compounds)		
82184	Ametryn	µg L^{-1}
39033	Atrazine	µg L^{-1}
38815	Hexazinone	µg L^{-1}
78064	Norflurazon	µg L^{-1}

Post stabilization Period

Stabilization is deemed to be achieved when the 12-month moving flow-weighted average TP concentration is less than or equal to 0.05 mg L^{-1}. Flow-proportional composite samples are collected at the outflow for compliance determination of the design objective of 0.05 mg L^{-1} TP concentrations. A method is included in the permit to account for extreme variability in hydrologic conditions.

Compliance of other parameters (Table 2), is assumed if there is no excursion from Class III water quality standards in outflow concentrations or outflow concentrations are lower than inflow concentrations. Details of compliance and non-compliance determinations are available in the permit (FDEP, 1997).

WATER QUALITY AND HYDROLOGIC MONITORING

Water Quality Monitoring

Water quality samples are collected at the inflow and outflow sites using various sampling methods and frequencies for the different types of parameters. Sample types used and frequency of sampling along with legends are shown in Table 3. Both grab and flow-proportional water quality samples are collected. Flow-proportional sampling volumes (trigger volumes) were set as presented in Abtew et al. (1997). Parameter groups from Table 2, sampling locations, frequency of sampling and sample type are shown in Table 4.

Table 3. Frequency of Sampling and Sampling Methods (Sample Types)

Frequency	Legend	Sample Type	Legend
Daily Averages of Continuous Sampling	DAV	Flow-Proportional Composite	FPC
Weekly	W	Tipping Bucket	TB
Biweekly	Bi-W	Ultrasonic Meter	UVM
Monthly	M	Grab	G
Quarterly	QTR	Pump Records Culvert Equation	PR CE

Table 4. Parameter Group, Sampling Location, Frequency and Sample Type

	Sampling Location	
	Inflow (G600)	Outflow (G607, G605, G606)
Parameter Group	Frequency (Sample Type)	
Flow	DAV (PR)	DAV (CE,UVM,UVM)
Physical	Bi-W (G)	Bi-W (G)
Nutrients	Bi-W (G)	Bi-W (G)
TP	W (FPC)	W (FPC)
Major Ions	QTR (G)	QTR (G)
Trace Metals	QTR (G)	QTR (G)
Pesticides-Water	QTR (G)	QTR (G)

Since STA6 officially began flow-through operations on December 9, 1997, TP concentrations at the outflow have been consistently lower than concentrations at the inflow. The preliminary net reduction in TP concentration is about 65%. Figure 3 shows the weekly comparison of inflow and outflow TP concentrations from December 15, 1997 to April 6, 1998. The average concentration of TP at the inflow (G600) was 0.057 mg L^{-1} and at the outflow (G606) was 0.018 mg L^{-1}.

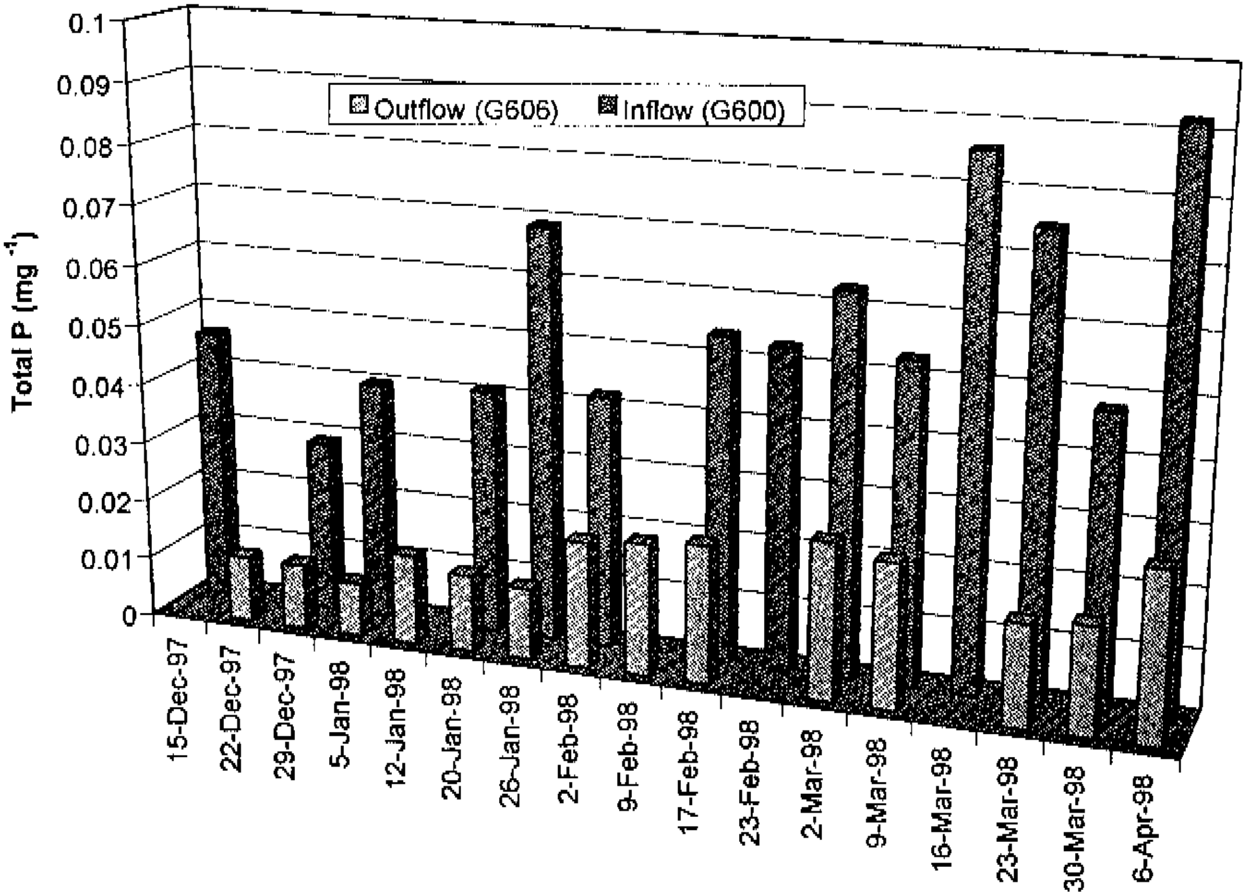

Figure 3. STA6, Section 1 Inflow and Outflow TP Concentrations.

Hydrologic Monitoring

Daily rainfall is measured with a tipping bucket gage. Stage (water levels) is measured at 15 locations. Table 5 shows all hydrologic monitoring sites, parameters, database keys and latitudes and longitudes of each site. The monitoring sites are also shown in Figure 2. Hydrologic data under the corresponding database keys are located in the District database DBHYDRO.

Table 5. Hydrologic Monitoring Stations, Parameter, Database Key and Location

Station	Parameter	Database Key	Lat.	Long.
G600_P	FLOW	G6531 (GG955*)	26° 21 '36"	80° 54' 21"
G605	FLOW	GA119 (H3143*)	26° 19 '55"	80° 52' 54"
G606	FLOW	GA116 (H3144*)	26° 19' 56"	80° 52' 53"
G607_C	FLOW	G7750 (GG956*)	26° 19' 53"	80° 52' 48"
G600_R	RAIN	G6530	26° 21' 36"	80° 54' 21"
G600_H	STAGE	G6528	26° 21' 36"	80° 54' 21"
G600_T	STAGE	G6529	26° 21 '36"	80° 54' 21"
G352S_H	STAGE	G6559	26° 21' 07"	80° 53' 56"
G352S_T	STAGE	G6560	26° 21' 07"	80° 53' 56"
G354C_H	STAGE	G6563	26° 20' 58"	80° 52' 51"
G354C_T	STAGE	G6564	26° 20' 58"	80° 52' 51"
G392S_H	STAGE	G6561	26° 20' 45"	80° 53' 37"
G392S_T	STAGE	G6562	26° 20' 45"	80° 53' 37"
G393B_H	STAGE	G6565	26° 20' 14"	80° 53' 37"
G393B_T	STAGE	G6566	26° 20' 14"	80° 53' 37"
G604_H	STAGE	GA117	26° 19' 56"	80° 52' 55"
G605	STAGE	GA118	26° 19' 55"	80° 52' 54"
G606	STAGE	GA115	26° 19' 56"	80° 52' 53"
G607_H	STAGE	FI260	26° 19' 52"	80° 52' 47"
G607_T	STAGE	FI261	26° 19' 52"	80° 52' 47"

* Preferred database keys with quality checked data sets

Inflow and Outflow monitoring sites are shown in Figure 2. The inflow pump station G600 is composed of five diesel pumps with a capacity of 2.83 $m^3 s^{-1}$ (100 cfs) each. Flow is computed for each pump as a function of static head and pump RPM. Two Handar 436B Incremental Shaft Encoders are installed to measure continuous upstream and downstream water levels. The RPM sensors used are the Airpax passive magnetic sensors that use variable reluctance technology (Airpax Instruments, Cheshire, CT). It consists a magnet, pole piece and coil. As a ferrous object approaches the tip of the pole piece, the magnetic field increases and then decreases as the object moves away from the pole piece. The snap of the rapid change in the magnetic field induces an AC voltage signal in the coil. The generated frequency signal is directly proportional to the number of ferrous objects passing the pole piece per unit time. The amplitude of the voltage output is proportional to the speed of the ferrous objects passing the pole piece. An aluminum split coupling with two magnets inserted into the coupling is attached to the shaft of each engine. These two magnets are mounted 180 degrees apart in the split coupling, and are used to generate the pulses in the Airpax passive magnetic sensors. The pulses generated by the Airpax passive magnetic sensors are wired to the CR10 Measurement and Control System's pulse input channels. The CR10 uses these pulses to calculate the actual RPM of the engines.

Communications between the Handar 436B stage recorder and the CR10 datalogger is accomplished via a Serial Digital Interface 1200 baud (SDI 12) line which allows multiple sensors to be controlled over a single three (3) conductor wire by the use of individual sensor addresses. Twelve

Volt Direct Current (12 VDC) power for each of the sensors is also delivered via this three wire interface. Stage and RPM measurements are made at one-second intervals to achieve the best accuracy in computing the accumulated flow necessary to trigger the autosamplers.

Head and tail water levels are recorded for computing flow at water control structures and for regulating water levels. Stages at G605 and G606 are monitored to compute flows from velocity measurements by the UltraSonic Velocity Meters (UVM). Field data is transmitted nightly via Radio frequency (RF) to a computer at the District Head Quarters. Routine and emergency maintenance procedures are implemented to maintain continuous data collection.

Daily distribution of rainfall, inflow and outflow rates at STA6, Section 1 is shown in Figure 4 for the period from November 1, 1997 to April 30, 1998. The daily average stage in each cell is shown in Figure 5. For the period, December 17, 1997 to April 30, 1998, the average stage in Cell 5 was 4.27 m (13.99 ft) NGVD and in Cell 3 was 4.275 m (14.02 ft) NGVD. Estimated average depth in Cell 5 and Cell 3 was 50.0 cm (1.64 ft) and 50.4 cm (1.65 ft) respectively. The total inflow to the project from December 9, 1997 (when discharge was granted) to April 30, 1998 was 3,148 ha-m (25,523 ac-ft). The total outflow from the project was 2,877 ha-m (23,324 ac-ft). So far, the average loading rate was 6.25 cm day^{-1} (2.46 inch day^{-1}) and the average retention period was 8.00 days. For the same period, the total amount of rainfall was 40.72 cm (16.03 inches). The monthly hydrologic summary is shown in Table 6.

Table 6. Monthly Hydrologic Data Summary

Year	Month	Rain (cm)	Inflow (ha-m)*	Outflow (ha-m)
1997	Dec*	12.56	893.78	1053.59
1998	Jan	2.77	562.06	486.60
	Feb	11.79	815.47	525.15
	Mar	12.85	769.59	649.58
	Apr	0.79	107.49	162.35

* 1 ha-m = 8.1068 ac-ft

* December 9 to December 31

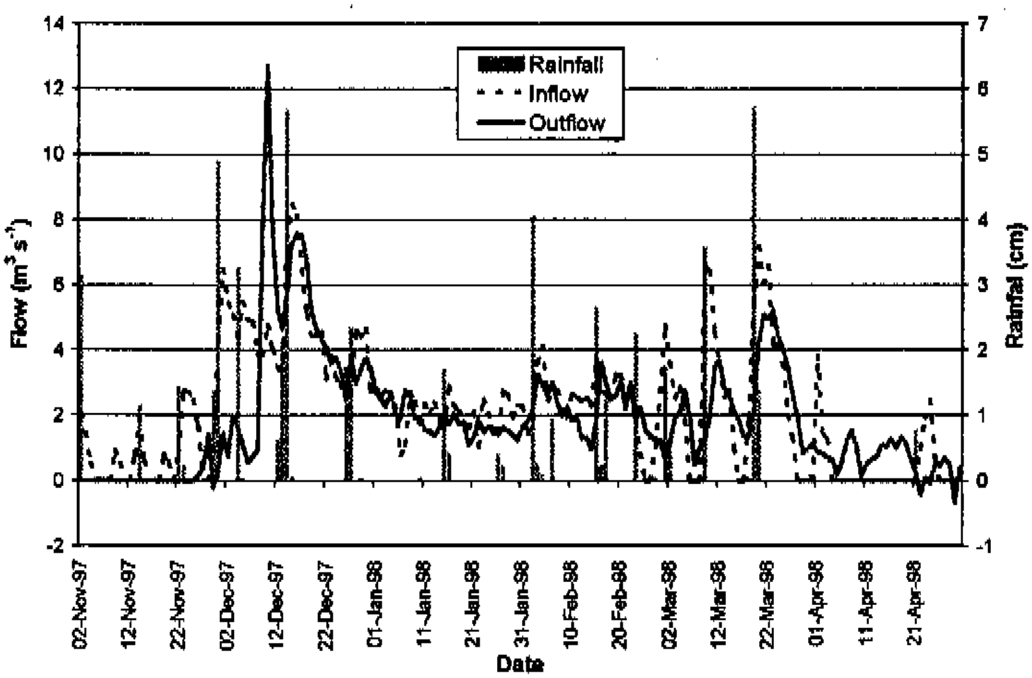

Figure 4. STA6, Daily Rainfall, Inflows, and Outflow Rates.

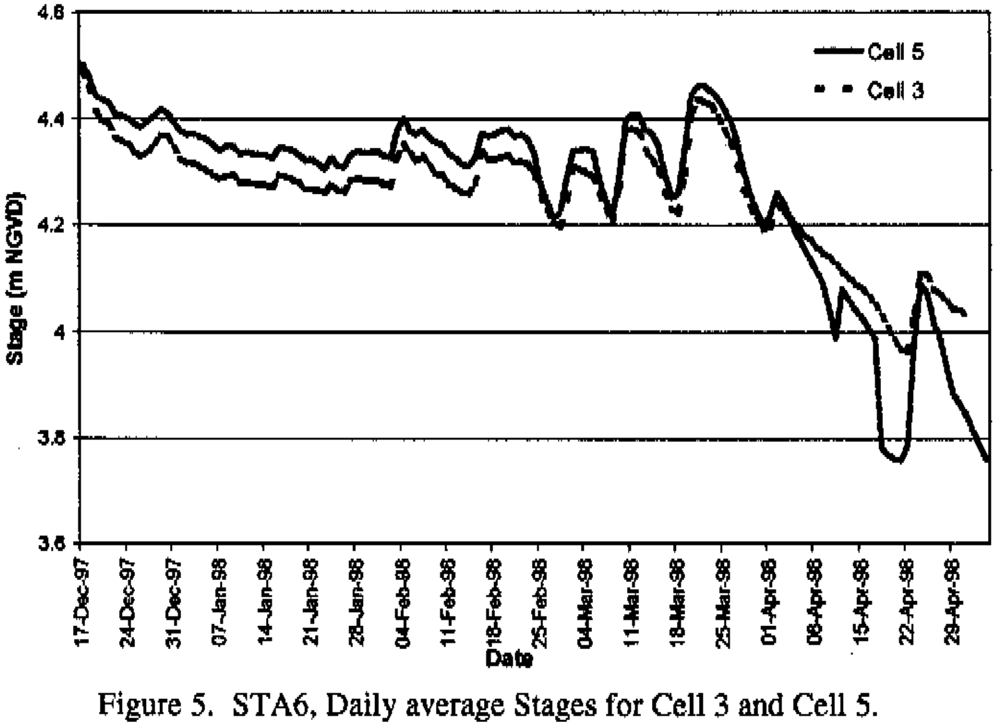

Figure 5. STA6, Daily average Stages for Cell 3 and Cell 5.

SUMMARY

Large scale agricultural runoff/drainage treatment using constructed wetlands has been demonstrated to be effective at the Everglades Nutrient Removal Project which has been under operation for the last four years. The addition of STA6, at the western edge of the EAA and the monitoring network will provide additional data that will help develop the management and optimum operation criteria for constructed wetlands. STA6 has gone through the startup phase. Stabilization is expected in two to three years. Continuous hydrologic and water quality monitoring will provide the essential data to develop water and chemical balances to gage the performance of the system.

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